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Investigation of the fuel value and the environmental impact of selected wood samples gathered from Brunei Darussalam

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ABSTRACT

Brunei Darussalam is located near the equator in the Borneo Island. Abundant rain, humidity and sunshine have created one of the largest rain forests in the world. Seven samples of sawdust taken from this rainforest and were analyzed for their fuel value and environmental impact. Among the seven variety of variety of wood investigated, one was soft, two were light, and four were of the hard type. Properties, such as wood density, ash content and elemental composition of plants were assessed and correlated with the calorific value. This was evaluated in relation to their properties and environmental impact when burned. It was revealed that the sawdust with the highest calorific value does not necessarily constitute the best option as fuel, if elemental composition is taken into account. The variation in wood density, calorific value, ash content and elemental composition of C, N and S along with their indirect impact on the environment are discussed in this paper.

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1. Introduction

The world's main source of energy is fossil fuel, which is non-renewable and rapidly diminishing. Alternative, renewable and unconventional energy sources can be found in Brunei Darussalam vast rain forest, which covers 78% of the island. This represents a significant untapped bio-energy resource.

Bioenergy is the conversion of biomass resources such as agricultural and forest residues, organic municipal waste and energy crops into useful energy carriers including heat, electricity and transport fuels.

Biomass is biological material derived from living, or recently living organisms. In the context of biomass for energy this is often used to mean plant based material, but biomass can equally apply to both flora and fauna derived material.

Biomass is carbon-based and is composed of a mixture of organic molecules containing hydrogen, usually including atoms of oxygen, often nitrogen and also small quantities of other atoms, including alkali, alkaline earth and heavy metals. These metals are often found in functional molecules such as the porphyrins which include magnesium-containing chlorophyll.

Biomass formation extracts carbon out of the atmosphere and returns it as it is burned. If biomass is managed on a sustainable

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basis, it can be harvested as part of a perpetually replenishable crop. This is either during woodland or arboricultural management of coppicing or as part of a continuous program of replanting with the new growth taking up CO_2 from the atmosphere at the same time as it is released by combustion of the previous harvest. This maintains a closed carbon cycle with no net increase in atmospheric CO_2 levels.

The choice of wood fuel is normally governed by the availability, the burning duration, the maximum temperature and the ash content [1]. Generally, hardwoods are preferred, as they have higher coal content, yield more heat and emit less smoke. But hardwood, like some *Eucalyptus* species, is not well regarded as fuel wood within rural communities [2]. As the commonly used wood species become scarcer, people often begin to use whatever fuel wood is available, without considering sustainability, ecological factors or the environmental effect.

The main physical properties affecting the performance of fuel wood are moisture content, chemical and elemental composition and wood density [3]. Increased moisture in the wood results in a subsequent decrease in obtainable heat, as more energy is used to evaporate water, which lowers the combustion efficiency [4]. For complete combustion it is necessary to evaporate the water present in wood. An investigation was undertaken to find the negative effect of moisture in wood on its calorific value [5]. Major elements contributing to the calorific value are carbon, hydrogen, nitrogen, oxygen and sulfur. The calorific value of wood can be related to its elemental composition and varies between 17 and 20 MJ/kg for oven dried wood [6].

A group of researcher [7] use cofiring sawdust with coal and trifiring sawdust with tire-derived fuel (TDF) and coal as a means for reducing NO_x emissions at its 188 MW cyclone boiler installed at the Willow Island Generating Station in West Virginia to reduce the NO_x emission as well as SO_x emissions. At the same time the biomass was intended to reduce SO_2 emissions, substituting sulfur-free biomass for coal. Mercury's emissions were also projected to decrease because the concentration of mercury in sawdust is about 2 orders of magnitude less than the concentration of mercury- in eastern bituminous coal. Finally, the generation of electricity with saw-dust reduces greenhouse gas emissions by substituting a renewable fuel for coal, thereby reducing the emissions of fossil-based CO_2.

Three bio-fuels: sawdust, charcoal and rice husk were burned in a biomass furnace dryer and their thermal powers were measured [8]. The result indicates that charcoal exhibits the highest thermal power followed by sawdust and rice husk. Its appropriate heating value might make sawdust suitable for sterilization of meat, fish, soup, etc.

In the present investigation the fuel value of one of the waste of timber industry, namely sawdust is taken into consideration.

A comparative performance of composite sawdust briquette with kerosene fuel during domestic cooking conditions is discussed by Kuti and Adegoke [9]. Controlled cooking test was carried out on three food items namely white yam, rice and white beans, respectively using composite sawdust briquette fuel and kerosene. Yam has the lowest specific fuel consumption (SFC) value of 012 kg/kg when sawdust briquette was used, 0.0635 kg/kg when kerosene was used. Rice had SFC of 0. 195 kg/kg when composite sawdust briquette was used and 0.0795 kg/kg when kerosene was used Beans had the highest SFC value of 0.32 kg/kg and 0.1425 kg/kg for composite sawdust briquette and kerosene respectively. On the other hand from the time spent to cook food items, yam has the lowest time spent in cooking per kg of 40.34 min/kg for briquette fuel and 36.36 min/kg for kerosene fuel. Rice has a cooking time of 40.38 min/kg for composite sawdust briquette and 31.1 min/kg for kerosene fuel. Beans had the highest cooking time of 75.83 min/kg for composite sawdust briquette and 74.7 min/kg for kerosene. From the result of carried out, the effect of the type of cooked food item on the SFC as well as the time spent in cooking 1 kg of food item is highly significant at 0.05 and 0.01 levels of significance. On the other hand, the effect of the type of fuel used for cooking on the SFC and the time spent in cooking per kg is not significant at any level of significance. There is no interaction between the type of cooked food item and the type of fuel used as levels of significance is low.

A fuel switching project was implemented for using the sawdust as an energy source replacing fossil fuels in the district heating systems [10]. The above was introduced in five medium sized towns in Romania.

Fuel briquettes generated by the low-pressure compaction of paper, sawdust, agricultural or yard waste, etc. currently serve as an alternative to firewood, wood pellets and charcoal in developing countries in Africa, Asia and South America [11]. Research at Boise State University in Idaho, explored both the calorific content and shape to optimize the burn efficiency of the bio-briquettes. The energy content of briquettes ranged from 4.48 to 5.95 kJ per gram (kJ/g) depending on composition, whereas the energy content of sawdust, charcoal and wood pellets ranged from 7.24 to 8.25 kJ/g. Bio-briquettes molded into a hollow-core cylindrical form exhibited energy output comparable to that of traditional fuels. The study demonstrates that low-energy content feedstock can be composted, pressed and combusted to produce heat output commensurate with higher energy content fuels.

A study was undertaken to assess the calorific value of briquettes produced from mixed sawdust of three tropical hardwood species (*Afzelia africana*, *Terminalia superba*, *Melicia elcelsa*) bonded with different binding agents (starch, cow dung and wood ash) [12]. Sawdust from each of the species was mixed with the binder in ratio of 70:30 cow dung and wood ash and 70:15 of starch. The sawdust where mixed in a ratio 50:50 for each briquette combination produced. Combustion related properties namely percentage volatile matter, percentage ash content, percentage fixed carbon and calorific value of the briquettes where determined. All processing variables assessed in this study were not significantly different except for percentage fixed carbon at five percent level of probability. The result shows that briquette produced from sample of *A. africana* and *T. superba* combination bonded with starch had the highest calorific value of 33,116 kcal/kg while briquette produced from sample of *A. Africana* and *T. superba* bonded with ash had the least calorific value of 23,991 kcal/kg. Since the aim of briquetting is to produce briquette that will serve as good source of fuel and support combustion, the best briquette was produced when sawdust was mixed with starch. This study shows that the use of mixed wood residue from the selected species and other hardwood species for briquette production will provide a cheaper alternative energy source to firewood for household heating application.

Elemental analysis can be used to describe biomass fuels, determine their calorific values [13] and their expected impact on the environment. This investigation is aiming to determine the best fuel wood by evaluating energy content and elemental composition for seven different available species.

In the present investigation, the wood density, ash content, calorific value and the elemental composition of the sawdust samples were determined. A simple credit system is developed that could help consumers to decide on the best option of fuel wood for heating purpose.

2. Materials and methods

2.1. Samples

All seven sawdust samples were collected from wood species investigated were native and readily available from the tropical

forest. In the present study, the following samples of sawdust were collected for analysis of wood density, calorific value, carbon, nitrogen, sulfur and ash content:

Agathis borneensis (Tulong), *Gonystylus* species (Ramin), *Shorea negrosensis* (Merant Merah Tua), *Dryobalanops rappa* (Kapur), *Dipterocarpus* species (Keruing), *Upuna borneensis* (Upun Batu), *Shorea* species (Selangor Batu).

The local names of the above species are given in the parenthesis.

2.2. Experimental methods

2.2.1. Calorific value

For the determination of the calorific value, a sample of the material to be tested was weighted accurately into a suitable crucible. The weight of sample was chosen to give a temperature rise of about 3 K, i.e. a heat release of about 30 kJ. A Gallenkemp Autobomb calorimeter was used with a pressure of 20 bar to determine the calorific value. The method used in the above investigation is based on as described in ASTM D240.

2.2.2. Wood density

The wood density was taken literature available from the Forestry Department, Government of Brunei Darussalam [14].

2.2.3. Ash content

The ash content was determined according to TAPPI standard T 211 om-85 [15]. Wood samples were weighed before they were placed in a furnace at 575 °C for 4 h.

2.2.4. Elemental analysis

The CNS analysis was done in the Elemental Analysis Laboratory of National University of Singapore using an Elementar Vario Micro Cube apparatus. The samples were weighed in a tin capsule and combusted in a furnace at 1150 °C. A conductivity detector is used to measure the evolved gas and determine the composition.

3. Results and discussion

The wood density, calorific value, ash content, carbon, nitrogen and sulfur content of seven sawdust species are represented in Table 1.

The wood density and calorific value of the seven wood species ranged from 480 to 1010 kg/m^3 and 11.55 to 21.65 MJ/kg, respectively. Bhatt and Todaria [16] described the average wood density and calorific value of several indigenous woody species of north east India in detail and obtained similar values, ranging from 638 to 983 kg/m^3 and 20.08 to 22.94 MJ/kg for wood density and calorific value, respectively. A higher wood density increases the calorific value and tends to slow the burning rate [17].

Table 1 illustrates calorific value, density, ash, carbon, nitrogen and sulfur content for the seven sawdust investigated.

From Table 1 it is found that, *Shorea negrosensis* has the poorest ash content, followed by *Shorea* species, *D. rappa*, *Gonystylus* species, *Dipterocarpus* species, *U. borneensis* and finally *A. borneensis*. The ash content is the remaining inorganic part of wood matter that cannot be combusted. A high ash content of a plant part makes it less desirable as fuel, because a considerable part of the volume cannot be converted into energy [18]. Lisardo et al. [1] described the softwood species show a lower ash content than the hardwoods despite possess higher calorific values. The difference in ash content is, however, statistically more significant than the difference in calorific values, which means that the wood with the highest calorific value is not necessarily the best option as fuel wood. However, it is not uncommon for such inefficient fuel woods to be used in small-scale boiler applications for heating purposes.

Fig. 1 shows as expected that the carbon content has an influence on the calorific value of the sawdust. Generally the higher the carbon content the higher the calorific yield. Though there is some discrepancy in the results for the two *Shorea* species. This discrepancy is presently unknown to the investigators.

The higher the carbon, nitrogen and sulfur content, the more likely is the formation of carbon monoxide, carbon dioxide, nitrogen/sulfur oxides, nitric acid and sulfuric acid. These emissions have a deleterious effect on environment. Wood after-combustion releases water and carbon dioxide into the atmosphere

Fig. 2 shows the calorific values (MJ/kg) as a function of density. It is generally found, that for four of the seven species the calorific values increases as density increased. But for the two *Shorea* species and for *Gonystylus* species it does not follow the above trend. It is thought that the above low value for *Gonystylus* species can be attributed to low carbon content (44.26%) compared to the other species. But the discrepancy for the two *Shorea* species is at present unknown to the researchers and need to be further investigated.

Lyons et al. [19] stated that in practice, oxidation of wood is not always complete and small amounts of carbon monoxide, hydrocarbons and other gases, such as nitrogen/sulfur oxides and fumes are also released. Some of these are harmful to health, some to the environment and some to the atmosphere. The latter are commonly called greenhouse gases. Pollutants such as carbon monoxide (CO), sulfur dioxide, nitrogen dioxide (NO_2) and particulate matter are of significance because of the effect they have on the environment and human health. Nitrogen oxide gases are produced by combustion. This can be produced from the nitrogen contained in the wood fuel and also from the oxidation of atmospheric oxygen at high temperatures. Nitrogen is oxidized to various nitrogen oxides (NO_x) and when NO_x and volatile organic compounds (VOCs) react in the presence of sunlight, they form a photochemical smog. This can be a significant contributor to air pollution [20]. Nitrogen oxides also play an important role in the atmospheric reactions creating ozone and acidic rain by the formation of nitric acid. Exposure to nitrogen oxides increases the risk of respiratory infections as it is highly toxic and irritating to

Table 1
Wood density, calorific value, ash content, carbon, nitrogen and sulfur content of evaluated sawdust species.

Local name	Scientific name (Abbreviation)	Density (kg/m^3)	Calorific value (MJ/kg)	Ash (%)	C (%)	N (%)	S (%)
Tulong	*Agathis borneensis* (Ab)	480	18.42	0.45	46.58	0.10	0.10
Ramin	*Gonystylus* species (Gs)	655	14.70	0.48	44.26	0.39	0.04
Merant Merah Tua	*Shorea negrosensis* (Sn)	720	12.60	1.13	47.03	0.46	0.10
Kapur	*Dryobalanops rappa* (Dr)	755	21.65	0.49	45.43	0.50	0.16
Keruing	*Dipterocarpus* species (Ds)	815	20.79	0.47	47.15	0.42	0.11
Upun Batu	*Upuna borneensis* (Ub)	995	20.42	0.47	50.2	0.37	0.05
Selangor Batu	*Shorea* species (Ss)	1010	11.55	0.63	46.38	0.41	0.04

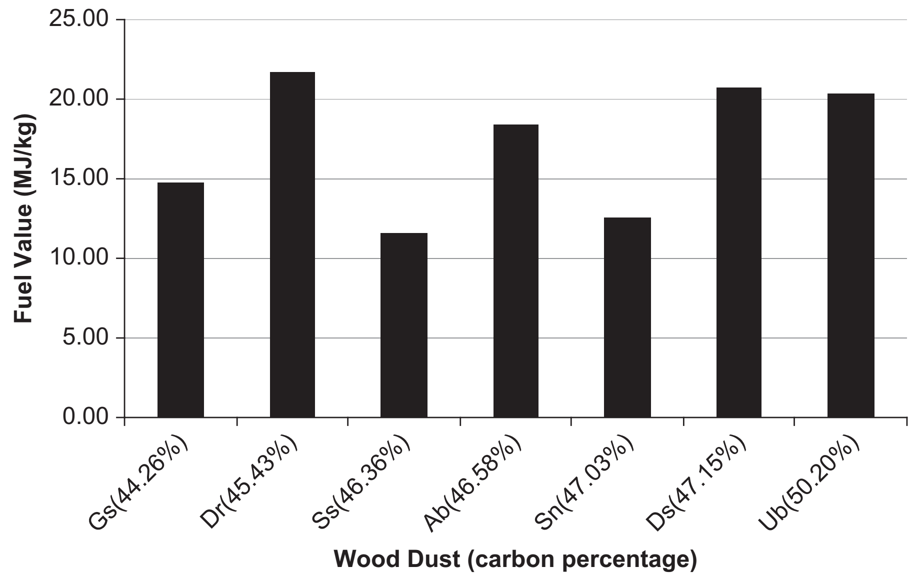

Fig. 1. Calorific value as a function of carbon percentage.

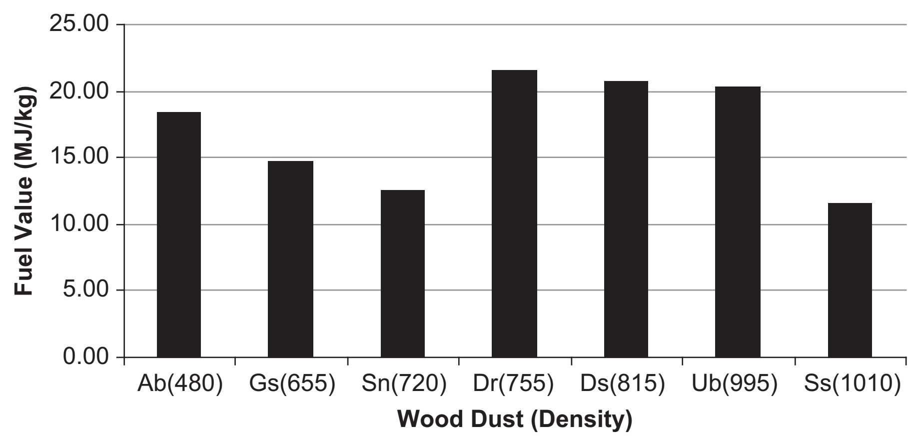

Fig. 2. Calorific value as a function of density.

Table 2
Rating of the wood species with the determined properties (1=best, 7=worst).

Properties	Species						
	Ab	Gs	Sn	Dr	Ds	Ub	Ss
Density	7	6	5	4	3	2	1
Calorific value	4	5	6	1	2	3	7
Ash content	1	3	6	4	2	2	5
Carbon	4	7	3	6	2	1	5
Nitrogen	1	3	6	7	5	2	4
Sulfur	3	1	3	5	4	2	1
Rating	3.33	4.17	4.83	4.50	3.00	2.00	3.83

the respiratory system. In this study the nitrogen content of the samples were determined, the above is a good indicator of the amount of nitrogen-based toxic components that can be formed.

Table 2 summarizes the properties of all seven investigated wood species and a rating in terms of energy output and an elemental composition. For each property, the samples were assigned a value between 1 and 7, with 1 being the best and 7 being the worst. The final rating value was determined as the sum of all values divided by the number of measured six properties [17]. Based on this final rating value, the preferred wood saw will be *U. borneensis* (2.00) followed by the *Dipterocarpus* species (3.00), *A. borneensis* (3.33), *Shorea* species (3.83), *Gonystylus* species (4.17). *D. rappa* (4.50) and *S. negrosensis* (4.83).

The wood species investigated in this study are commonly used by the sawmilling industry in Brunei Darussalam but seldom used as fuel wood. The main consumers of this lumber are likely (semi-) urban inhabitants. The lumber is used in construction, furniture fabrication, and making power transmission poles. The sawdust produced by these lumber mills is unfortunately not utilized in any fuel application. However, this paper shows the value of tapping into this unused energy resource and in fact provides a comparison of different types of sawdust that may be used. Based on the findings it may be possible select the best fuel alternative that balances both energy output and environmental impact. It can be mentioned that compared to other energy sources [21], wood combustion also has the lowest acid impact per unit of energy. When all contributions of the components involved in energy production are taken into consideration, wood combustion has the lowest greenhouse gas and acid precipitation impact per unit of heat delivered among the various energy options.

4. Conclusion

The results of this study shows that that the calorific value should not be the only factor to be taken into account when evaluating fuel value for sawdust, but elemental composition and negative environmental impact should also be considered. An attempt has been made to show the dependence of calorific value on carbon content and density. Though for most of the species the calorific value increases with both carbon content and density, two *Shoera* species proved to show a contrary relationship. Further investigation is needed to understand why such an exception exists. *A. borneensis* is the preferred species with regards to low nitrogen and ash content, followed by the *Gonystylus* species. Ultimately, *U. borneensis* is the best among the seven sampled species after balancing the costs and benefits.

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